California Environmental Protection Agency

Environmental Technology Certification Program

Evaluation of EnvirOzone Technologies, Inc.
Advanced Oxidation System
Model EOT-AOX 1000

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I. Introduction

This report discusses the Model EOT-AOX-1000 Advanced Oxidation Process for the treatment of municipal wastewater. The report will cover the performance claims to be verified by the California Environmental Technology Certification Program (CalCert), the results of the pilot study performed at the East Bay Municipal Utility District, and the findings and recommendations by the California Environmental Protection Agency (Cal/EPA) staff regarding this technology.

A. Certification Program

Effective August 19, 1996, Section 71011 and 71031 of the California Public Resources Code (PRC) directs all California Environmental Protection Agency (Cal/EPA) Boards and Departments, including the State Water Resources Control Board (SWRCB), to adopt a voluntary statewide program to certify the performance of environmental technologies. The SWRCB adopted the Implementation Policy for Environmental Technology Certification Program at a September 1997 Board meeting with Resolution 97-078-CWP. This Policy allows proponents of a technology to request that the SWRCB staff conduct an independent third-party verification of performance claims focusing on the water quality benefits of the technology.

In accordance with this Policy, SWRCB staff has evaluated EnvirOzone Technologies, Inc.'s Advanced Oxidation System Model EOT-AOX-1000. This report was prepared to show the results of this evaluation. The evaluation is based on a detailed review of validation materials submitted by the manufacturer and original data generated by an independent laboratory, whose findings were considered reliable by SWRCB staff. This Certification is strictly a performance certification and does not imply that the technology has been permitted for any application. The information contained in this report may, however, be used by a regulatory agency as background and performance information that may be needed to achieve an environmental permit. The permitting authority is maintained by the applicable environmental permitting agency.

B. Overview of Regulatory Process for Technology Sector

The State of California has tasked the Regional Water Quality Control Boards (RWQCBs) to regulate the State's water quality. The RWQCBs utilize many regulatory mechanisms to ensure water quality objectives. One of these mechanisms is through the issuance of waste discharge permits.

Waste discharge permits for wastewater treatment plants commonly identify fecal coliform requirements as a measure for the disinfection level achieved by the wastewater treatment process. Fecal coliform, measured as a most probable number per 100 milliliters (MPN/100ml), is an accepted indicator for the presence of disease-causing waterborne pathogens.

Ozone and ultraviolet (UV) irradiation are two accepted treatment mechanisms to reduce or inactivate human pathogens in water. This Certification Report evaluates an advanced oxidation process utilizing both ozone and UV irradiation as a means of achieving human pathogen reduction in a municipal wastewater effluent stream.

The target treatment level of 23 MPN/100 ml will satisfy many standard permit requirements, where human contact is not probable. However, when human contact is possible, the RWQCBs may choose to follow the water recycling criteria adopted by the Department of Health Services (DHS) where the beneficial use of a surface water is equivalent to the direct beneficial use of reclaimed water. Where reclaimed water is applied to unrestricted recreational impoundments having human contact, the DHS requires that the total coliform in the reclaimed water is limited to 2.2 MPN/100 ml (Title 22, California Code of Regulations, Section 60301.230 and 60305). The treatment technology must also demonstrate the ability to remove viruses. While the DHS regulations do not apply to wastewater discharges, they provide a guide to the RWQCBs when drafting permits for discharges into water bodies having equivalent beneficial uses. In addition to this example, there may be other situations where discharge limitations may be more restrictive than 23 MPN/100ml.

C. Certification Limitations

The SWRCB makes no express or implied warranties as to the performance of the manufacturer's product or equipment. Nor does the SWRCB warrant that the manufacturer's product or equipment is free from any defects in workmanship or matters caused by negligence, misuse, accident, or other causes.

SWRCB staff believes, however, that the manufacturer's product or equipment can achieve performance levels set out in this Certification. Our determination is based on data submitted by the manufacturer and the use of the product in accordance with the manufacturer's specifications. This certification does not relieve the manufacturer of procurement of any permits required by local or state authorities governing wastewater treatment.

By accepting this Certification, the manufacturer assumes, for the duration of the Certification, responsibility for maintaining the quality of the materials and equipment at a level equal or better than was provided to obtain this Certification and agrees to be subject to quality monitoring by Cal/EPA.

II. Performance Claim

The EnvirOzone Technologies Advanced Oxidation System Model EOT-AOX-1000 claims to effectively reduce fecal coliform levels in municipal secondary treated wastewater effluent when the system is properly installed, operated, and maintained in accordance with the manufacturer's guidelines as described in the "Operation and Maintenance Manual". This evaluation report will certify that EnvirOzone's EOT-AOX-1000 can consistently, within a 95% confidence interval, reduce fecal coliform levels in municipal secondary treated wastewater effluent to less than 23 MPN/100 ml. This certification will be applicable to *only* the medium-pressure lamp configuration and the following influent and operating parameters.

Influent parameters at the entrance to the system:

- Water temperature between 58^{o}F and 79^{o}F
- Water pH between 6.0 and 7.0
- Water transmittance greater than 25 percent
- Fecal coliform count less than 80,000 MPN/100ml

And operating conditions as follows:

- Ozone dosage greater than 9.4 mg/l
- UV dosage greater than 36.7 mJ/cm^2
- Ozone concentration of at least 7%
- Feed rate up to 1,000 gpm

Each of the performance claim criteria previously described is based on the operating conditions experienced during the Model EOT-AOX-1000 examination period. The determination of these values will be discussed in Section VI – System Testing and Evaluation.

III. Materials Available for Evaluation

The following materials were applied as part of our evaluation of the EnvirOzone Technologies, Inc. Advanced Oxidation System Model EOT-AOX-100 performance claim:

1. California Environmental Technology Certification – Application for Certification Advanced Oxidation Process, August 23, 1999.

2. EnvirOzone Technologies, Inc. Model EOT-AOX-1000 & Model EOT-OZ-1000 Operation and Maintenance Manual.

3. EnvirOzone Technologies 1,000 gpm Pilot Study Prepared by East Bay Municipal Utility District and EnvirOzone Technologies, Inc. Final Report, May 1999.

4. A revised claim for certification of the EOT-AOX-1000 including tables containing the data supporting the claim concerning the reduction in fecal coliform count, a set of raw data on disc, and listing of the analytical procedures used for testing, Letter to Dan Little (SWRCB), received December 29, 1999.

5. Certification Claims for EnvirOzone Technologies, Inc. Wastewater Treatment System – Model EOT-AOX-1000, Letter to Dan Little (SWRCB), March 8, 2000.

IV. Scientific Basis for Technology

The Model EOT-AOX-1000 process applies ozone oxidation and ultraviolet irradiation to disinfect wastewater effluent. The ozone process oxidizes organic compounds and subsequently reduces the color and odor of the wastewater. The ability to reduce color enhances the treatment performance of the ultraviolet irradiation by increasing the percentage of ultraviolet transmittance described hereinafter.

The ozone process impacts the organics present in the wastewater effluent by breaking the bonds of the compound on the molecular level; this includes the long chain molecules classified as complex organic compounds. Once the ozone process begins to break down the complex organic compounds, it will typically create a greater concentration of simpler organic compounds. Ideally, these smaller organic compounds are more volatile and easier to biodegrade.

Ultraviolet irradiation utilizes radiation with a wavelength range of 240 to 280 nanometers to photochemically damage the deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) with in the cells of the target organisms. Since the DNA and RNA of the cells carry the genetic information for cell reproduction, the disease-causing organism can effectively be inactivated by their impairment. The near optimal operating wavelength for disinfection is typically described as 253.7 nm, which is the primary wavelength of a low-pressure UV lamp. The medium-pressure lamp generates a broad polychromatic output across the UV spectrum with about 25 percent in the region ranging from 200 to 300 nm. The higher intensity makes medium-pressure UV systems suitable for disinfecting waters of lower quality that are contaminated with a larger variety of organic compounds. These waters are characterized by low transmissivity, 50 percent or less, and require a higher radiation intensity to provide the penetration needed for disinfection. However, the wider range of radiation means that less of the applied power is used to produce germicidal wavelengths, resulting in higher energy consumption.

The performance of the UV disinfection system will be a function of the UV dosage distributed throughout the wastewater, measured in microwatt-seconds/square centimeter or millijoules/square centimeter. The UV dosage will be a function of the distance that the radiation has to travel through the wastewater stream, the exposure time, the intensity of the UV light, and the transmittance of the water. UV transmittance is a measure of the quantity of light at the characteristic wavelength of 253.7 nm transmitted through the target liquid per unit depth expressed as a percentage. As the UV lamps emit radiation, the intensity will attenuate as the distance from the lamp increases; this is simply due to the dissipation or dilution of the energy as the volume it occupies increases. A second attenuation mechanism involves the actual absorption of the energy by chemical constituents contained in the wastewater, such as the Total Suspended Solids (TSS) concentration or color.

Further oxidation occurs when ozone is exposed to UV irradiation and hydroxyl radicals (OH^-) are formed. Hydroxyl radicals are many orders of magnitude more powerful oxidants than ozone. Thus residual ozone in the wastewater stream is converted to hydroxyl radicals by UV and is available to continue inactivating pathogens and/or oxidize organic compounds that may be present. As previously mentioned, the Model EOT-AOX-1000 is also claimed to reduce the content of certain complex organic compounds and hydrocarbons contained in municipal secondary treated wastewater effluent. For the purpose of this evaluation report, only the claim for the system’s disinfection capability, the reduction of fecal coliform levels, will be addressed.

V. Technology Description

The EnviOzone Technologies' Advanced Oxidation System Model EOT-AOX-1000 is a packaged advanced oxidation plant that incorporates ozone generation, ozone injection via Mazzei Injectors with a specific gas/liquid ratio, pressurized detention, entrained gas removal, and ultraviolet irradiation. According to the manufacturer, this system accomplishes microbial disinfection and oxidation of organic compounds contained in mixed residential effluent and industrial secondary wastewater effluent and industrial wastewater, at flow rates of up to 1,000 gallons per minute. The process is patented by U.S Patent No. 5,180,499 and the apparatus is patented by U.S Patent No. 5,308,480.

The process utilizes a specific gas/liquid balance, ozone concentrations, and UV irradiation. In addition to deodorizing and disinfecting, ozone increases the transmittance of the water, thus allowing the UV system to be a more effective disinfectant.

The Model EOT-AOX-1000 is built from components supplied by multiple manufacturers. The manufacturing company mounts the components on skids, allowing for modular installation in accordance with EnvirOzone's specifications. At EBMUD, the equipment was delivered on four skids: (1) the ozone system, (2) the injection system, (3) the retention tanks, and (4) the UV system. The equipment was off-loaded and connected on site on a concrete slab.

This process has four stages – ozone generation, ozone injection and mixing, contact chamber and UV irradiation. The ozone generation process uses three Ozonia Ozat Ozone Generators Type CF-5, each capable of producing 85 pounds per day of ozone at a concentration of 6 percent by weight. The ozone injection and mixing process utilizes GDT's patented process where two in-line Mazzei venturi type ozone injectors draw the ozone from the ozone generators and mix it with the influent wastewater stream received from the treatment plant's secondary clarifier(s). The injectors use the vacuum created at the throat of the venturi-type injectors to pull the ozone gas into the wastewater stream.

Because pressure increases the solubility of ozone, the system includes a booster pump, which can be used to increase the inlet pressure up to 75 pounds per square inch (psi) and the outlet pressure up to 30 psi. As ozone enters the water stream, it is mixed and entrained in the form of small bubbles providing a greater surface area for the gas to liquid mass transfer. After passing through the ozone injectors, the water enters a 1,400 gallon vessel allowing the ozone to transfer and/or dissolve into the water. The contact time in the vessel is about one and a half minutes. The water then enters a degassing vessel where the gaseous O_2, O_3, and other gaseous products of the reaction are separated from the water via centrifugal forces. The off-gas is then sent to the ozone destruct unit.

The ozone off-gas destruct unit scrubs residual ozone gas and discharges to the atmosphere. A demister unit installed before the ozone destruct unit removes moisture from the off-gas stream. This moisture or water is separated and drained to the effluent stream. The off-gas destruct process converts residual ozone contained in the contact vessel vent gasses into oxygen by contact with a catalyst, manganese dioxide-copper oxide (MnO_2-CuO). The vent gas is first heated as it flows by the destruct unit recirculation heater to prevent water condensation on the catalyst and to thermally decompose the ozone. Because ozone decomposition is an exothermic reaction, it releases its own heat, enabling further thermal decomposition. Heated vent gas flows through the catalytic chamber where the catalyst converts this residual ozone to oxygen. The oxygen and other gases, such as carbon dioxide, then exit the chamber and are released to the atmosphere.

The retention process uses two 10,000-gallon vessels (V-3 and V-4 in the schematic) to allow time for ozone contact and oxidation. The vessels are designed with stationary tabs that provide for uniform flow and continuous mixing of the water and ozone. The vessels are plumbed to allow operation in series or bypassing of one or both. Each vessel is operated with a hydrostatic head. Vent lines are installed at the top of each vessel and routed to the ozone destruct unit. Pressure regulating valves at the ozone destruct unit allow the gas to be vented as necessary to maintain the desired pressure in the contact vessels. A level controller controls the water level in each tank.

The EOT-AOX-1000 ultraviolet light systems are equipped with two types of UV units: a low-pressure unit and a medium-pressure unit. Each unit is designed for a maximum flow rate of 500 gpm. The low-pressure unit consists of two banks of lamps connected in series, each containing 20 lamps. The medium pressure unit consists of a single 4-lamp bank. The lamps in both systems are isolated from direct water contact by quartz sleeves, and the medium-pressure system is equipped with wipers, which automatically clean the quartz sleeves allowing efficient transfer of UV energy to the water.

Monitoring equipment is located throughout the system including: influent and effluent flow meters, pressure gauges, ozone concentration meters, and temperature indicators. Sampling ports are located at various points in the process train. Alarms are installed for identifying equipment malfunctions and unsafe operating conditions. Red lights on the alarm panel identify high ozone levels in the area surrounding the injectors, the ozone destructor vent stack, and the ozone generator building. The ozone generators have individual alarms if leaks are detected within the generators. An amber light on the alarm panel indicates malfunctions in the UV units, such as lamp expiration. The EOT-AOX-1000 is powered from the main electrical grid. The system, as evaluated, did not have provisions for standby power.

A. Operational Modes

The Model EOT-AOX 1000 offers different operational modes in an effort to accommodate fluctuating system needs. The pilot study applied each of the configurations in order to evaluate the different schematic's effectiveness at reducing both organic contaminants and fecal coliform. The four operational modes are briefly described in the following table.

Operational Mode	Mode Description	Total Retention Volume (gallons)	Design Flow Retention Time (minutes)
A	Post-ozone injection mixing and two-tank retention	21,400	27
B	Post-ozone injection mixing and one-tank retention	11,400	15
C	Post-ozone injection mixing only	1,400	2
D	Recirculation with booster pump and two-tank retention	21,400	27 per pass

Figure 1 is a process flow diagram, in Operational Mode A, of the EnvirOzone Technologies Model EOT-AOX-1000 advanced oxidation system as tested. Operational modes B, C, and D, are similar, differing only in the total retention volume and design flow retention time, which can be changed by the opening or closing of the valves as indicated on the diagram. A brief discussion of the applicability of each configuration is described below:

Operational Mode A: Full-system operation with maximum retention time; the longer retention time would likely be implemented to address a higher organic concentrations.

Operational Mode B: Partial-system operation with reduced retention time. With each contact vessel adding about ten minutes to the process, the system takes less time by eliminating one of the contact vessels and can only target a lower concentration of organics.

Operational Mode C: This mode completely bypasses the mixing vessels, which streamlines the system for fecal coliform treatment only. This also creates the fastest processing time of just over two minutes, which is the minimum operational time allowable through system design.

Operational Mode D: Full-system operation with recirculation. This is designed to treat the more persistent organics that would not be effectively treated with only one pass. This setup would likely be more suitable for a remediation site contaminated with a high level of organics.

EnvirOzone staff did perform an experimental Operational Mode E that offered a fifth configuration. The system was configured to run from the ozone reaction chamber and degasser directly to the UV chamber (same as mode C). Following the UV chamber, the system was then pumped to the retention vessels to increase the overall retention time. The experiment was designed to examine if the hydroxyl radicals would increase with extended retention time following the UV irradiation.

The pilot study revealed that additional retention time had little effect on improving the fecal coliform reduction, therefore, this certification will not specify which operational mode is required because the minimal operational mode (mode C) is still adequate for reducing fecal coliform.

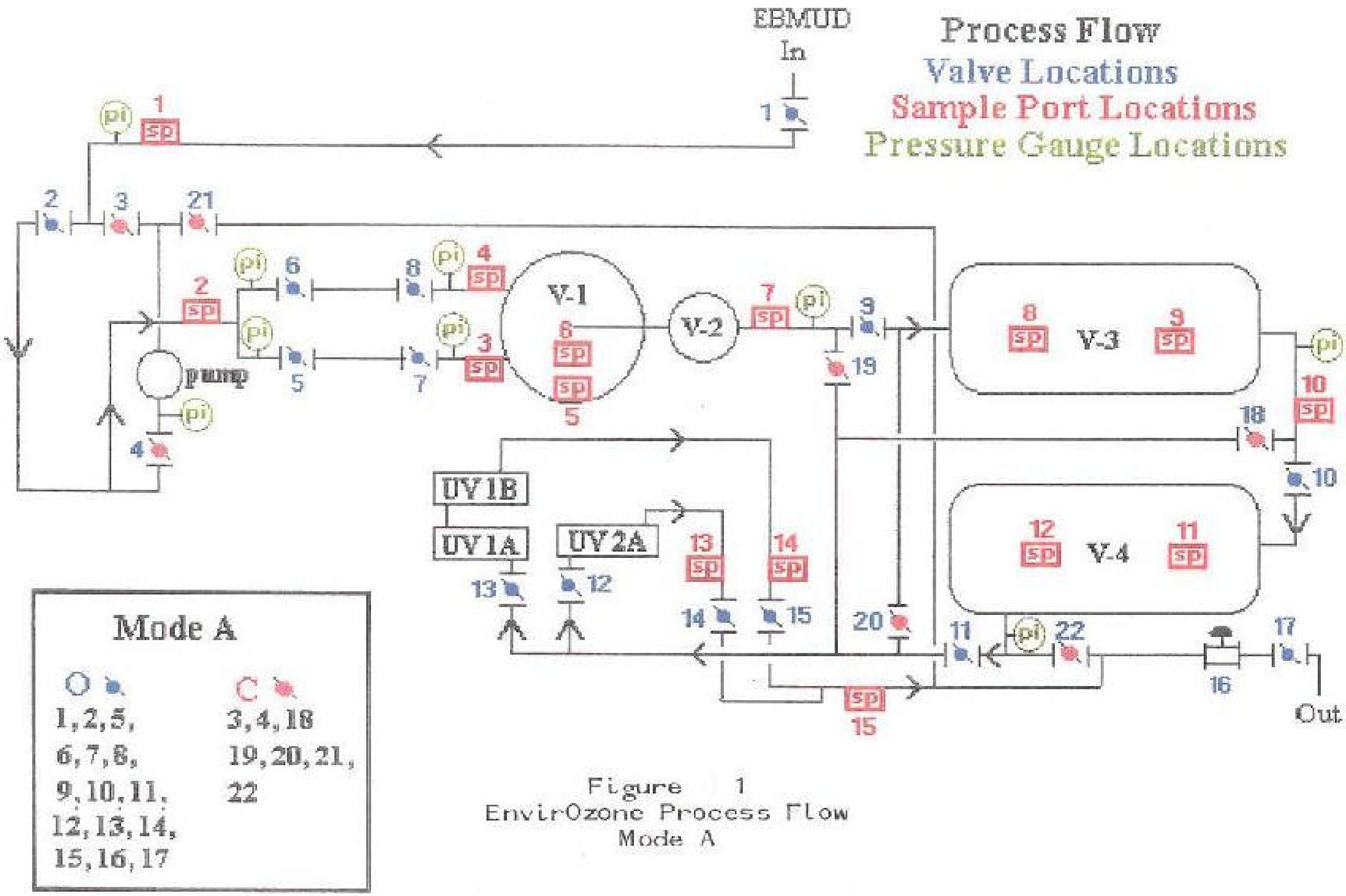

Figure 1
EnvirOzone Process Flow
Mode A

VI. System Testing and Evaluation

A. Test Location

The EOT-AOX-1000 system was pilot tested at the East Bay Municipal Water District's (EBMUD) Main Wastewater Treatment Plant (MWWTP) in Oakland, California. The MWWTP is a municipal wastewater treatment plant that provides secondary wastewater treatment for urban Alameda County including Oakland, Berkeley, and Alameda. The wastewater influent at the MWWTP is a mixture of domestic, commercial, and industrial wastes. The commercial sources include auto repair, dry cleaning, photo processing, printing, warehouse, and furniture stripping facilities, and the industrial sources include pharmaceutical and food processing companies. The key wastewater treatment processes for the liquid train at the MWWTP include primary clarification, biological treatment using activated sludge, secondary clarification, disinfection using sodium hypochlorite, and dechlorination using sodium bisulfite.

The 1,000 gallon per minute pilot plant was installed at the EBMUD plant in the summer of 1998, and the pilot study began in September 1998. The purpose of the pilot study was to evaluate the system's technological feasibility, consideration of medium-pressure UV as a disinfection process, and additional potential benefits such as destruction of hydrocarbons and other complex organic compounds. For the purpose of this evaluation report, the wastewater stream tested was undisinfected effluent received from the secondary clarifiers at the EBMUD treatment plant.

The samples included in this performance claim were selected based on the criteria outlined in Section II. If the samples were outside of these operating parameters, they were eliminated from the statistical analysis. The data was collected from September 1998 through June 1999. The EBMUD report on the pilot study was concluded in February 1999, but EnvirOzone continued the analysis through June

1999. This report includes the additional data supplied by EnvirOzone's extended pilot study.

B. Testing Protocol and Procedures

The EBMUD EnvirOzone Pilot Study was divided into five testing phases consisting of a Preliminary Phase and Phases One through Four. Each phase focused on different testing parameters such as ozone dose, ozone concentration, UV influent pressure, operational mode, and UV dose.

Secondary effluent was delivered to the pilot plant prior to chlorination. Since the purpose of this study was to analyze this technology's ability to reduce fecal coliform levels, only influent and effluent fecal coliform levels are presented. Table 1 contains the data used for this analysis. The data analysis does not include influent coliform concentrations below 2,200 MPN/100ml because samples below this level are abnormally low for undisinfected secondary effluent.

C. Data Quality Assurance/Quality Control

The EBMUD Laboratory collected, prepared, and analyzed all of the samples. The EBMUD laboratory is accredited under the Environmental Laboratory Accreditation Program (ELAP) 1060 issued by the State of California Department of Health Services. In summary, the following Quality Assurance/Quality Control measures were followed, and EPA Test Methods were used where applicable, including:

Analyte	Test Method
Fecal Coliform Count	SM(18)9221E
UV Absorbance	SM 5910 – Modified
pH	EBMUD Field Data

D. Data Analysis

The data collected during the pilot study was compiled in an electronic database (reference material #4). The data was then screened according to various criteria in an effort to identify the minimum effective performance level for individual parameters. The acceptable performance level for each parameter is what is identified under the performance claim in Section II.

In order to establish effective operating parameters, it was necessary to evaluate the Model EOT-AOX 1000 system working backward from the UV chamber, where the majority of disinfection occurs. The higher UV transmittance percentages observed in the medium-pressure UV chamber correlated well with increasing disinfection performance; the lower transmittance levels experienced less consistent disinfection to the target levels. In order to refine the qualifying data, a minimum UV transmittance level was established; the lowest acceptable transmittance percentage entering the UV chamber was determined to be 36%.

Prior to reaching the UV chamber, the ozone process is designed to increase the transmittance level. At a minimum ozone dose of 9.4 mg/l, the ozone chamber was observed to increase UV transmittance by an average of 12% over the percent entering the ozone chamber. Although, the 12% increase was not consistently observed if the transmittance entering the ozone chamber was below 25%. Therefore, the minimum allowable transmittance entering the ozone chamber was determined to be 25%. With an average increase of 12% in the ozone chamber, wastewater flow with a transmittance of 25% entering the ozone chamber would exit the ozone chamber at 37% transmittance.

The data was examined once more applying these latest criteria, and it was determined that the minimum medium-pressure UV dose allowable would be limited to 36.7 mJ/cm^2.

The upper flow rate is a limiting factor by design of the system. The water temperature and pH limitations were calculated by using the extremes observed during the pilot study.

Table 1

Data Samples within Operating Parameters

Operational Mode	Fecal Coliform Influent (MPN/100 ml)	UV Transmittance Entering System (%)	Ozone Dose (mg/l)	UV Influent Pressure (psi)	UV Transmittance Entering UV Chamber (%)	Medium-Pressure UV Dose (mJ/cm2)	Fecal Coliform Effluent (MPN/100ml)
C	23000	25.1	10.5	20	38.9	118.5	2
A	17000	26.9	13.1	10	38.0	36.7	2
C	16000	36.3	10.2	15	57.5	154.3	2
B	8000	44.7	12.5	15	49.0	84	2
B	5000	25.1	16.1	10	37.2	44.6	2
C	3000	25.1	13.6	15	39.8	86.3	2
C	3000	28.2	13.6	15	36.3	86.3	2
B	2300	26.9	10.4	20	37.2	60.5	2
B	2200	29.5	12.8	15	39.8	84	2
E	70000	30.2	9.4	15	41.7	53.9	4
C	28000	26.9	10.9	20	37.2	60.5	4
C	23000	29.5	10.5	15	40.7	84.7	4
C	17000	27.5	9.9	10	41.7	39.2	4
B	13000	36.3	16.1	10	55.0	44.6	4
B	2300	42.7	16.1	10	58.9	44.6	4
C	3000	31.6	9.9	10	44.7	39.2	7
B	3000	32.4	9.7	15	45.7	65.7	7
C	80000	36.3	21	15	44.7	65.7	8
B	50000	47.9	9.7	15	58.9	65.7	8
B	23000	49.0	10.4	15	55.0	44.6	8
B	7000	55.0	9.4	10	56.2	44.6	8
C	80000	34.7	10.2	20	58.9	44.1	11
B	50000	39.8	15.6	15	64.6	39.2	11
A	50000	44.7	13.1	10	63.1	36.7	13
B	50000	44.7	9.4	10	60.3	44.6	13
B	50000	45.7	10.4	15	60.3	44.6	13
B	5000	41.7	9.4	10	60.3	44.6	13
A	80000	47.9	13.9	10	64.6	36.7	17
B	17000	49.0	9.7	15	64.6	65.7	30
C	11000	41.7	9.9	10	56.2	39.2	30
A	14000	56.2	18.2	15	72.4	70.8	50

VII. Conclusions

The pilot study performed at the East Bay Municipal Utility District with the EnvirOzone Technologies, Inc. Model EOT-AOX-1000 Advanced Oxidation System yielded an adequate amount of successful data for analysis. The Model EOT-AOX-1000 can be successfully operated to achieve a maximum fecal coliform concentration of 23 MPN/100 ml when both the wastewater influent and the system operation meet the parameters outlined in Section II – Performance Claim.

This conclusion is based on the data points that were screened to determine the limiting performance level of each parameter. The screening eventually revealed the 31 data samples listed in Table 1. The table reveals the following operating maximum and minimums:

Fecal Coliform Influent:	2,200 to 80,000 MPN/100 ml
UV Transmittance Entering System:	25.1 to 66.1%
Ozone Dose:	9.4 to 21 mg/l
UV Influent Pressure:	10 to 15 psi
UV Transmittance Entering UV:	36.3 to 79.6%
Medium-Pressure UV Dose:	36.7 to 158.5 mJ/cm^2
Fecal Coliform Effluent:	2 to 50 MPN/100 ml

Wastewater transmittance at the EBMUD plant varied widely according to EBMUD engineers. For example, early in the workweek, secondary effluent transmittance ranged from 50 to 60 percent. Transmittance decreased to around 20 to 30 percent in the latter part of the workweek mainly due to industrial discharges to the MWWTP, while previous studies at the District have observed wastewater transmittance below 10 percent. It is highly recommended that the potential users of the EOT-AOX-1000 advanced oxidation system carefully analyze their secondary wastewater effluent stream transmission over a period of time to determine the potential capability of the UV component of the EOT-AOX-1000 system.

Operational modes were used interchangeably throughout the testing. There was no readily apparent correlation between the operational mode (system retention time) and the effectiveness of the pilot plant's disinfection capability. The system was effective throughout this range at reducing the coliform count.

The feed rate to the UV system ranged from an estimated 521 to 1048 gallons per minute. There was no apparent correlation between the system's disinfection effectiveness and flow rate. The system was effective throughout this range at reducing coliform count. Water temperature ranged from 58°F to 79°F with no apparent loss of effectiveness at reducing the coliform count in the wastewater.

These results were obtained using only a portion of the data points collected. Certain data points were excluded from the statistical analysis. Data points representing influent coliform counts below 2,200 MPN/100 ml were excluded because they were not deemed to accurately represent undisinfected secondary effluent in that the water stream may have been inadvertently disinfected prior to discharge to the pilot plant. In addition, particular instances revealed fecal coliform reduction from 300,000 to 2 MPN/100 ml; however, because this was not achieved consistently and not within the testing parameters this data was not evaluated.

This evaluation report should not be used as a basis for estimating or determining the performance of the Model EOT-AOX-1000 outside of the range, performance parameters, or operating conditions discussed previously in this section and in the performance claim. The results and the statistical analysis contained herein are not valid for influent coliform samples containing greater than 80,000 MPN/100 ml.

For examples and references of statistical analysis performed for this evaluation see Appendix A.

VIII. Recommendations

The results of the testing indicate that EnvirOzone Technologies, Inc. performance claim has been validated and the EOT-AOX-1000 is a viable disinfection process for the specified influent parameters and operating conditions stated in Section II of this document. The Model EOT-AOX-1000 performed in accordance with the performance claim for this particular application. Each application's influent stream should be carefully evaluated to ensure adequate constituent parameters for EOT-AOX-1000 disinfection success.

Appendix A

Sample Statistical Calculations

The following equations and calculations were used for statistical analysis of the Model EOT-AOX-1000 test data:

From <u>*Probability and Statistics*</u>*, Lindgren, McElrath and Berry, 1978*:

a. **Mean:** $$\mathbf{X = (\sum X_i) / n}$$

where X is the mean value

X_i is the value for a test data

n is the number of test data

b. **Standard Deviation:** $$\mathbf{S = \sqrt{\sum (X_i - X)^2 / n}}$$

where S is the standard deviation value

n is the number of test data

X is the mean value

X_i is the value for a test data

c. **Confidence Interval:** $$\mathbf{C.I. = X \pm t_{.95} * S / \sqrt{n}}$$

where C.I. is the upper and lower value for which there is a 95% probability that data in a specified set (specified by X, S and n) will fall between the upper and lower value

S is the standard deviation value

n is the number of test data

X is the mean value

$t_{.95}$ is the critical value of the t-distribution value for a confidence interval of 95%